



*Age of the Universe:
2 Billion Years*

COSMIC TIMES

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*Size of the Universe:
280 Million Light Years*

Andromeda Nebula Lies Outside Milky Way Galaxy Spiral Nebulae are indeed “Island Universes”

Astronomer Edwin Hubble, of the Mount Wilson Observatory at Pasadena, California, has solved the mystery of the spiral nebulae. The spiral nebulae look like hazy pin-wheels in the sky. He has determined that these objects are much more distant than previously thought. Therefore, they are distant galaxies and not part of our own Milky Way galaxy. In the process, Dr. Hubble was also able to determine the distance to the spiral Andromeda nebula.

Dr. Hubble's observations support the views Dr. Heber Curtis expressed in a debate with Dr. Harlow Shapley in 1920. Curtis stated that bright diffuse nebulae are fairly close to Earth and are part of the Milky Way, while spiral nebulae are at great distances and not part of the Milky Way.

On December 30, 1924, Hubble announced that he had taken photographs of a few bright spiral nebulae with the Mount Wilson Hooker telescope, the largest reflecting telescope in the world. According to Dr. Hubble, “The 100 inch reflector partially resolved a few of the nearest, neighboring [spiral] nebulae into swarms of stars.” One of the nearby nebulae Dr. Hubble photographed was the Andromeda nebula. He estimates it is as large, and holds as much matter, as the Milky Way. It may contain some three to four billion stars that produce one-billion times the light of the Sun



Edwin Hubble at the Mount Wilson Observatory

These photographs showed there were individual stars in the nebula. They also showed some of the stars changed in brightness over time. Known as Cepheid variable stars, these stars were the key to determining distances to the nebulae. The true brightness of the Cepheids, in the nebulae Hubble studied, was known from how the Cepheid changes its brightness. Scientists had known for many years exactly how light dims over distance. The distance to the star, and the nebula it is located in, can be found by comparing the apparent brightness of these stars to their true brightness.

Dr. Hubble's work builds on earlier observations by Miss Henrietta Swan Leavitt of the Harvard College Observatory and by Dr. Harlow Shapley of the Mount Wilson Observatory.

In 1912, Miss Leavitt was the first to recognize the importance of Cepheid variables. They are giant stars, and each varies in brightness over time. Cepheids are named after the first such star of its type found: Delta Cephei in the constellation Cepheus. While studying Cepheids in the Small Magellanic Cloud, Miss Leavitt noticed that the Cepheids would brighten, then fade, and then brighten again. The length of time (the period) it took for the star to go through this cycle was directly related to its true brightness: the longer the period, the brighter the star. The Small Magellanic Cloud is a large group of stars visible in the southern hemisphere. Since all of these stars

were in the Small Magellanic Cloud, they were at roughly the same distance from the Earth. Each Cepheid's true brightness was directly related to its period.

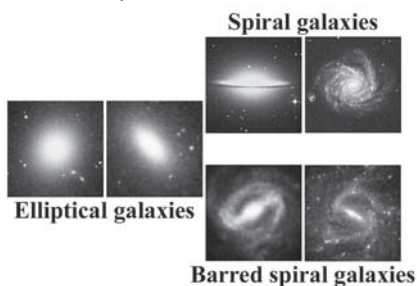
Soon after Miss Leavitt's discovery, Dr. Shapley began searching for Cepheids in globular clusters in our own Milky Way galaxy. Globular clusters are sphere-shaped groups of tens of thousands of densely packed stars. He used the period-brightness relationship to determine the distance to more than 230 globular clusters. He assumed that Cepheids in distant globular clusters act the same as nearby Cepheids. Based on that assumption, he found the most distant clusters in the Milky Way Galaxy are about 200,000 light years away.

By studying the periods of the Cepheids in the Andromeda nebula, Dr. Hubble was able to determine the true brightness (or absolute magnitude) of each. He then made observations of their apparent brightness (or apparent magnitude). Once he knew the difference between how bright a star appeared and how bright it truly was, he was able to calculate its distance from the Earth. He found Andromeda to be 900,000 light years away -- the most distant object known to-date.

Classifying Nebulae

For over a thousand years, astronomers wondered about the nature and development of nebulae. Nebulae appear to be faint clouds of gas and dust in the distant universe. Until recently, there have not been enough observations to classify nebulae based on their features or qualities.

During his studies of the spiral nebulae Dr. Hubble proposed a system to classify all nebulae. He sorted them into three basic categories: elliptical, spiral, and irregular. These categories were further subdivided according to shape (spherical to elongated ellipses, for example) and structure (hazy to distinct spiral arms, barred spirals, etc.).



Hubble's system shows a sequence of evolutionary change but was "based primarily on the structural forms of photographic classification which should be entirely independent of theoretical considerations". Future astronomical studies and evidence will be the test for this new classification system.

Universe is Expanding "Red Shift" is Proof of Einstein's General Theory

Using the 100-inch Hooker Telescope at Mount Wilson Observatory, Dr. Edwin Hubble has studied many spiral nebulae. He has discovered they are moving away from us at a rapid pace. This is strong evidence of an expanding universe. He has further determined that the farther the nebulae, the faster it moves away.

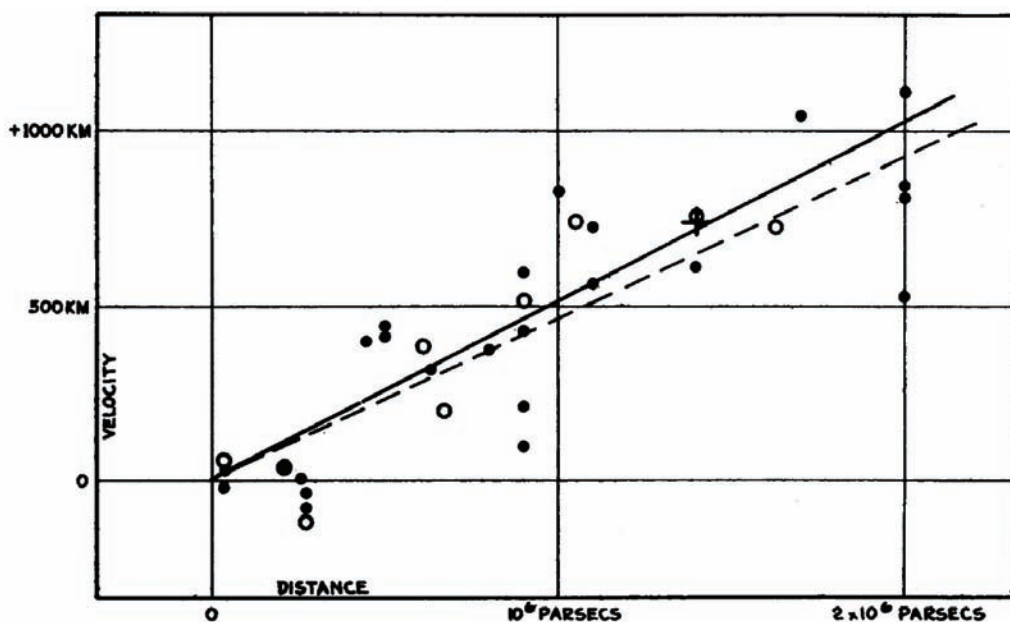
Hubble and colleague Milton Humason measured the speeds and distances for twenty-four of these nebulae. Because they are moving so quickly, their light waves (electromagnetic spectra) are stretched out. Because red light has the longest wavelength, this phenomenon is known as "redshift". The team noticed that dimmer, more distant objects have a larger redshift than objects closer to Earth. As reported in a recent paper, Hubble's measurements led him to a useful speed-distance relationship: redshifts increase in direct proportion to their distance from us.

"Dr. Hubble determined distances to the twenty-four nebula using Cepheid variable stars. These are stars that astronomers use to determine the distance to the nebulae they are found in. Once he knew how far away the nebulae were, he could compare their distance to their red-shift to learn the relationship. He concluded that the most distant objects are speeding away from us at perhaps thousands of miles per second."

Dr. Hubble's recent discoveries show that the volume of space itself is expanding. Spiral nebulae appear to be moving away from each other at a rate that increases with distance, but these nebulae aren't just moving. They are being pulled along as space expands.

Hubble's findings build on the work of Dr. Vesto M. Slipher of Lowell Observatory in Flagstaff, AZ. In 1912 Dr. Slipher first recorded the electromagnetic spectra of spiral nebulae. All but a few of the forty spectra Slipher later gathered were very red-shifted. This means almost all of them were moving away from us. However his studies lead him to a conclusion that speeds for the nebulae might be closer to only 600 miles per second.

Although Hubble's work presents a big breakthrough in our understanding of the Universe, one big question remains. How far out into the Universe does his model hold? The 100-inch telescope can clearly show Cepheids in only the nearest nebulae. In very distant nebulae, where Cepheids are barely visible, Hubble uses the brightest individual stars, some 50 to 100 times brighter than the Cepheids, as standard candles.



Hubble's diagram showing the relationship between galaxy distance and velocity

Today's telescopes, and the stars they see, will only take Dr. Hubble so far. To measure even greater distances, astronomers will need a larger telescope and new types of standard candles.

One new instrument may hold the key. Last year the Rockefeller Foundation agreed to provide six million dollars to fund the construction of a new observatory with a 200-inch telescope. This new telescope will collect four times more light than the 100 inch telescope Hubble currently uses.

Einstein's General Theory Holds True

The past decade has been an exciting and challenging time in the development of scientific understanding of the Universe. During this time scientists have been testing their ideas about the Universe against Einstein's 1916 theory of general relativity. The theory describes the universe as three dimensions of space (length, width, and depth) and one of time. It says that gravity curves this space-time and that the curvature controls the natural motions of objects in space.

Einstein's theory also suggested the expansion of the Universe, but Einstein didn't believe this could be correct. In 1917 he added a new term to his equations, the "cosmological constant." This constant was designed to avoid the possibility of an expanding universe. Hubble's recent observations remove the need for this term. While Einstein has examined the data and believes Dr. Hubble's paper to be sound, he is still not convinced the universe is expanding.

In 1922, Soviet scientist Alexander Friedman developed his own solutions to the general relativity equations.

He described two possibilities for the Universe: either it was expanding or contracting, but it was not staying the same.

Abbe George Lemaître, a Catholic priest and astronomer released a paper in 1927. This paper said a homogeneous universe of constant mass has to be expanding to account for the speed of spiral nebulae moving away. He described a possible universe that was expanding from an initial single point. Lemaître believed that before this expansion began, the Universe did not exist.

Hubble's discoveries answer many questions, but they also present a new direction for the future studies of the Universe.

In Their Own Words

New observations by Hubble...make it appear likely that the general structure of the Universe is not static.
- Einstein - 1925

Tomorrow the outlook may change and new methods may dwarf our knowledge and beliefs of today, or convert them into remote history. Soon we may look far beyond the last frontier, now 140,000,000 light years away. We, or our successors, may actually know familiarly the farthest borders of this vast Universe and learn facts about it so astounding that astronomers of today would be nearly unable to comprehend their significance.

- Edwin Hubble - 1927

“Great Debate” Resolved

Dr. Hubble’s discovery settles the “Great Debate” over the size of our own Milky Way galaxy. It also settles the distance to spiral nebulae and what they are.

Held on April 26, 1920 at the National Academy of Sciences in Washington, D.C., the debate focused on the opposing views of astronomers Harlow Shapley and Heber D. Curtis.

Shapley’s studies led him to describe the Milky Way as an enormous galaxy of stars some 300,000 light years across. This is much larger than most previous estimates. He also said the solar system is far from the galaxy’s center and that all nebulae, including spiral nebulae, are located within the Milky Way.

Using photographs he had taken as evidence, Dr. Curtis presented his idea that spiral nebulae were “island universes”, or distant star systems similar to the Milky Way. They were not a part of the Milky Way galaxy. He also believed the Milky Way was less than 30,000 light years in diameter and 8,000 light years in thickness.

Dr. Hubble’s recent observations support Curtis’ views. While bright, diffuse nebulae are relatively close and part of the Milky Way, spiral nebulae are separate systems located far away from it. He estimates the spiral Andromeda Nebula is as large and holds as much matter as the Milky Way. However, Hubble’s findings also support Shapley’s ideas about the Milky Way’s size and the location of the solar system.

Shapley’s work had increased the size of the Universe by about ten times, but Hubble’s recent discoveries have multiplied it by at least another ten. Shapley observed a historical progression, from belief in a small universe with man at its center, to a larger one with Earth further from the center: “The significance of man and the Earth...has dwindled with advancing knowledge of the physical world...”

The Minds atop Mount Wilson

High above Pasadena, California in the San Gabriel Mountains, the astronomers at the Carnegie Institution’s Mount Wilson Observatory are changing our view of the Universe. Who are these scientists?

Athlete-Scholar Unveils the Future of the Universe

Born in Marshfield, Missouri in 1889, Edwin Powell Hubble’s early life centered on athletics, primarily track and field events. At 6 foot 3 inches in height, he was quite successful, even setting an Illinois state record for the high jump.

At the University of Chicago, he focused on mathematics and astronomy. His studies took a different direction when he attended Oxford University as a Rhodes Scholar. There he studied Roman law and Spanish but still made time to compete in water polo and field events. He returned to the US in 1913 to teach high school physics and Spanish.

The next year, Hubble returned to the University of Chicago to earn his PhD and began researching faint nebulae at the Yerkes Observatory. However, his research was interrupted when the US entered the Great War and he quickly joined the army. Hubble served in France until the end of the war. Then he returned to civilian life to take up a position that had been offered to him two years earlier at the Mount Wilson Observatory

Former Mule-Team Driver and Janitor Helps Discover Expanding Universe

Milton Lasalle Humason was born in Dodge Center, Minnesota in 1891, but moved to California with his family as a child. Having left school in the eighth grade, Humason received no formal training as an astronomer. In fact, his career at Mount Wilson began as a mule-team driver for the pack trains that carried large parts of the telescope and its building to the top of Mount Wilson during the observatory’s construction.

When the telescope was completed 1917, Mr. Humason was hired as a janitor and electrician. His intelligence and curiosity were soon noticed, and it wasn’t long before he was promoted to night assistant on the 60-inch telescope.

Working under the observatory’s director, Dr. George Ellery Hale, Humason became an expert observer. Dr. Hale recognized his abilities and appointed him to the observatory’s scientific staff in 1919. Humason soon became an expert at measuring the redshifts of distant nebulae and the chief assistant and co-worker with Dr. Hubble.